SST Climate Data Records

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MODIS Calibration Workshop
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Outline

- What is a Climate Data Record?
- Can we generate an SST Climate Data Record from MODIS data?
- Yes we can!
    - But it is not easy.

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Desired SST CDR uncertainties

CDRs of SSTs require most stringent knowledge of the uncertainties:

- Target accuracies: 0.1K over large areas, stability 0.04K/decade - Ohring et al. (2005) Satellite Instrument Calibration for Measuring Global Climate Change: Report of a Workshop. *Bulletin of the American Meteorological Society* **86**:1303-1313

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Reference to SI units

The First Recommendation of the 20th Conférence Générale des Poids et Mesures :

"*that those responsible for studies of Earth resources, the environment, human well-being and related issues ensure that measurements made within their programs are in terms of well-characterized SI units so that they are reliable in the long term, are comparable world-wide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Convention du Mètre*"

See http://www.bipm.org/jsp/en/ListCGPMResolution.jsp?CGPM=20

Laying the foundations

- Provides a basis for consistent long-term records from a variety of sources.
- Provides consistency between different groups making related measurements.
- For satellite-derived sea-surface temperature, it provides a mechanism for consistent time series to be generated over multiple missions.

Climate Data Records

- National Academy of Sciences Report (*NRC, 2000*): “***a data set designed to enable study and assessment of long-term climate change, with ‘long-term’ meaning year-to-year and decade-to-decade change****. Climate research often involves the detection of small changes against a background of intense, short-term variations.”*
- *“Calibration and* ***validation should be considered as a process that encompasses the entire system****, from the sensor performance to the derivation of the data products. The process can be considered to consist of five steps:*
  - *instrument characterization,*
  - *sensor calibration,*
  - ***calibration verification,***
  - ***data quality assessment, and***
  - ***data product validation.****”*

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How can we generate SST CDRs?

- Satellite radiometers may be well-calibrated and well-characterized prior to launch, but is this sustained through launch and on orbit? Constant monitoring of instrument performance is required
- Accurate brightness temperatures measured in space do not necessarily mean accurate SSTs, as effects of imperfect atmospheric corrections dominate.
- SST CDRs require SI traceability: can be achieved by estimating rates of degradation or through **validation programs**.

AATSR

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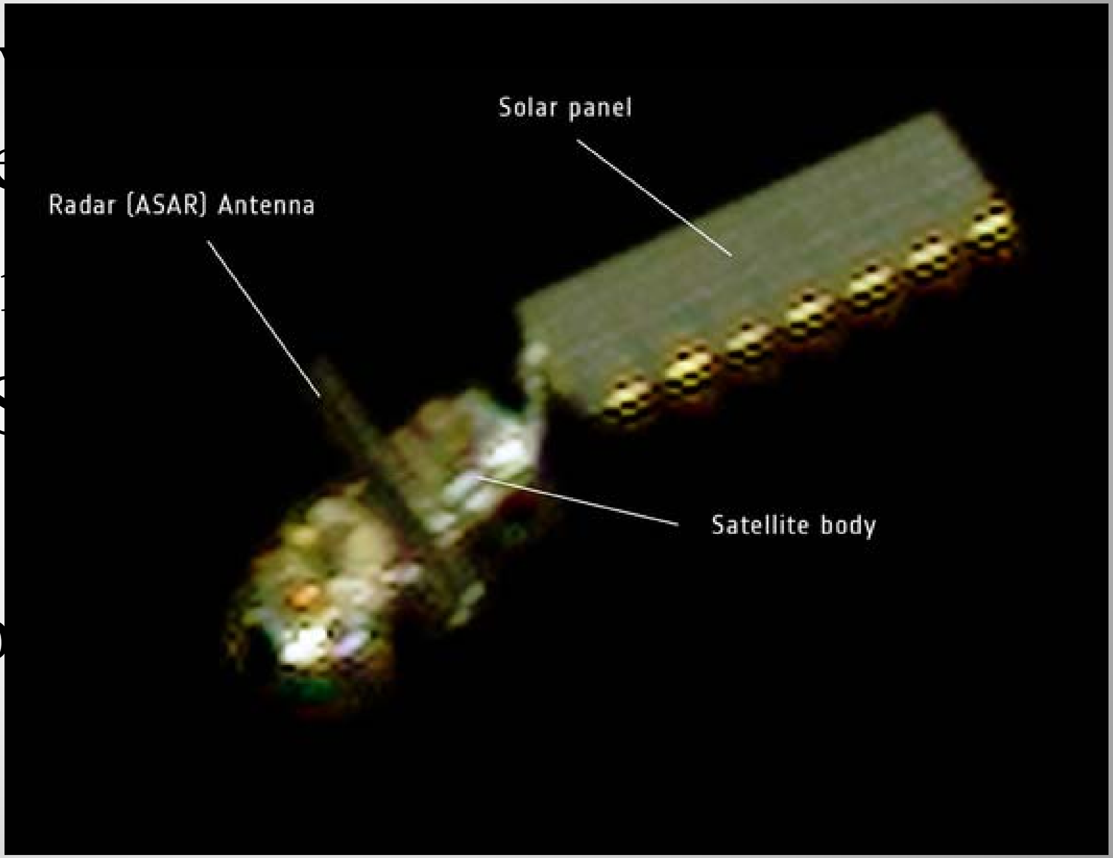
  2015.
- Climate focus o



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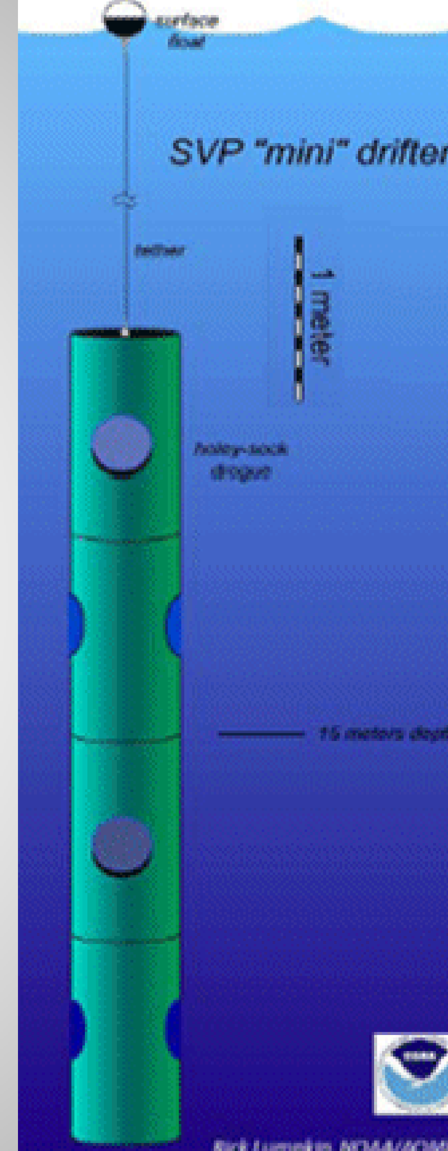
Temperature measurements from drifting buoys

- Deployed from ships and aircraft.
- Telemeter data via satellite links.
- Measure SST and P_o
- Satellites determine position.
- Changes in positions from day-to-day give surface currents; often with a drogue.



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Drifting buoys

Before & After

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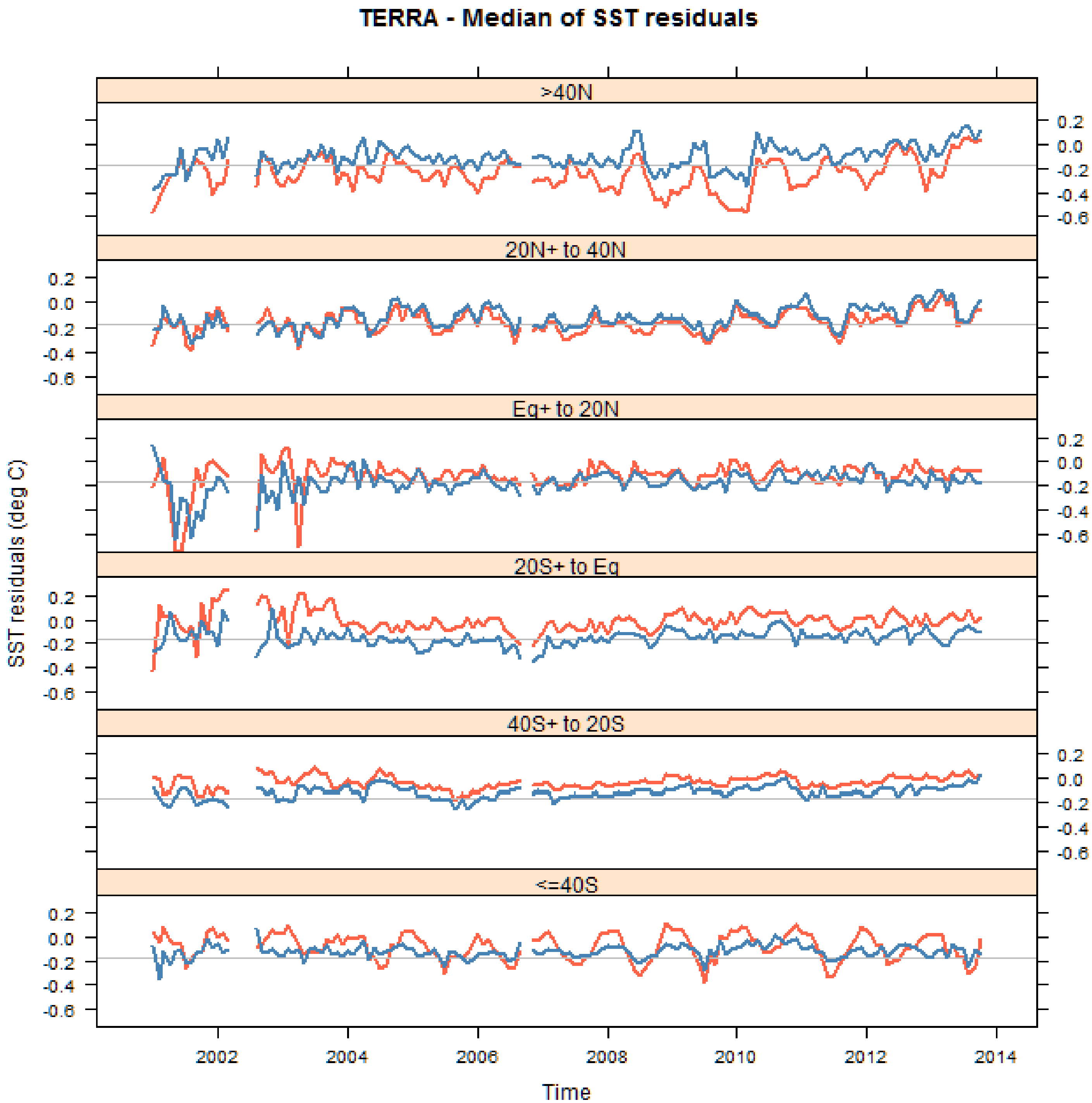
Issues with drifters

- Uncertainty is ~0.23K
- Calibration drift post-deployment?
- Temporal sampling irregular
- Spatial sampling is irregular
- Sub-surface temperature measurements
- Drogues tend to become detached, changing measurement characteristics



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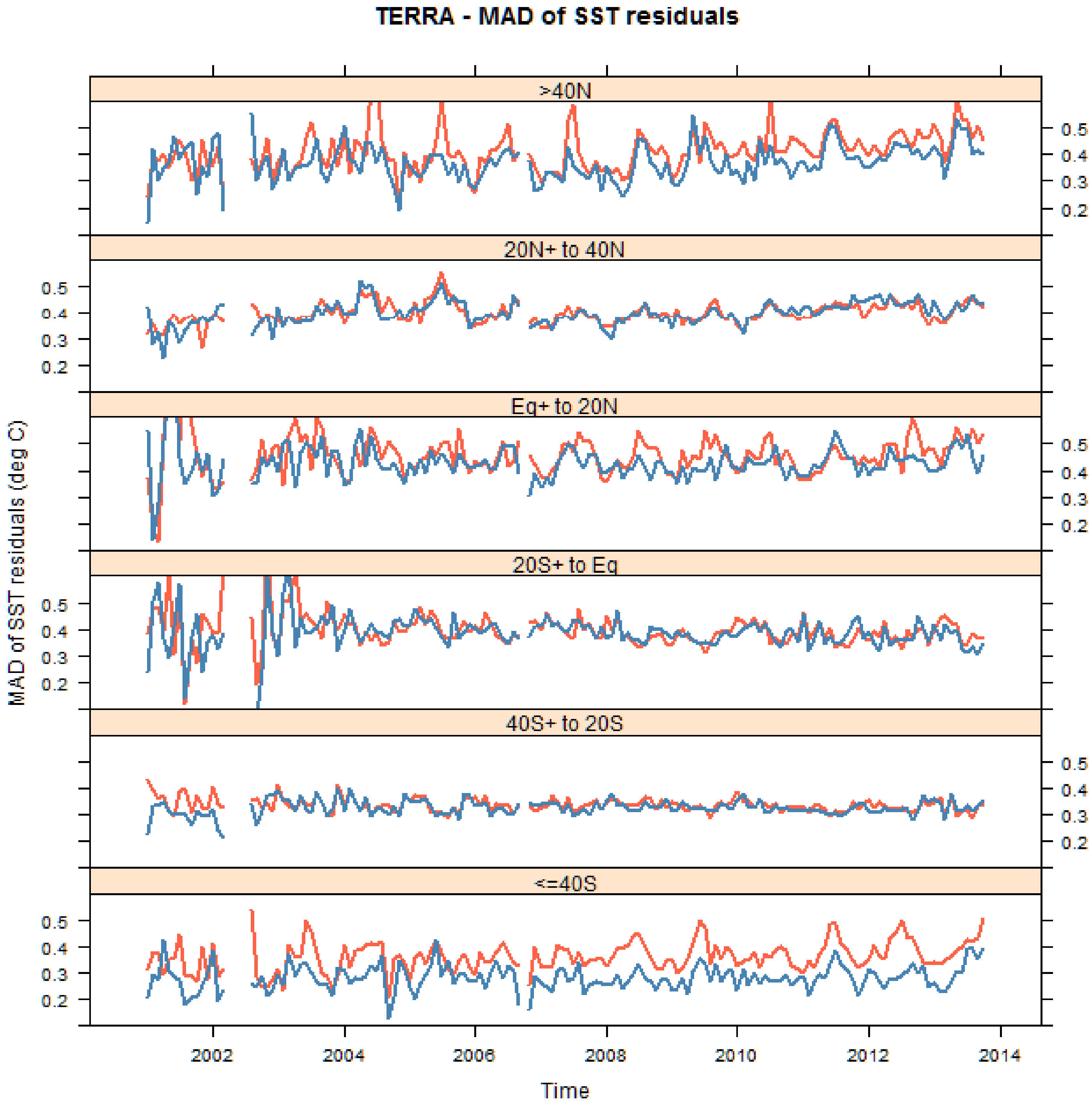

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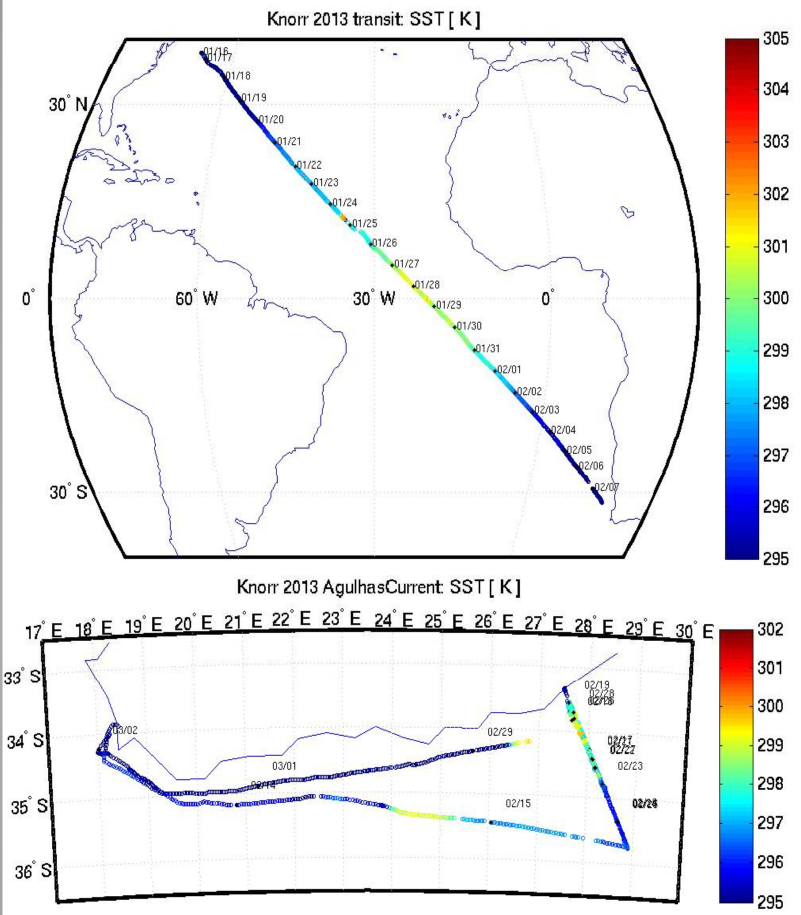
SST validation: ship-board radiometers

- Ship-board radiometers measure the skin SST – the surface layer of the ocean that emits the radiation measured by infrared satellite radiometers.
- Ship-board radiometers are self-calibrating and this is repeatedly assessed using SI-traceable facilities. Provides an "unbroken chain" of comparisons from at-sea measurements to SI-standards in National Metrology Institutes.
- This is an important prerequisite for generating a Climate Data Record of Sea Surface Temperature.
- Repeated calibration and characterization of the ship-radiometers allows estimation of uncertainties in the SST validation system.

Ship radiometers: M-AERIs



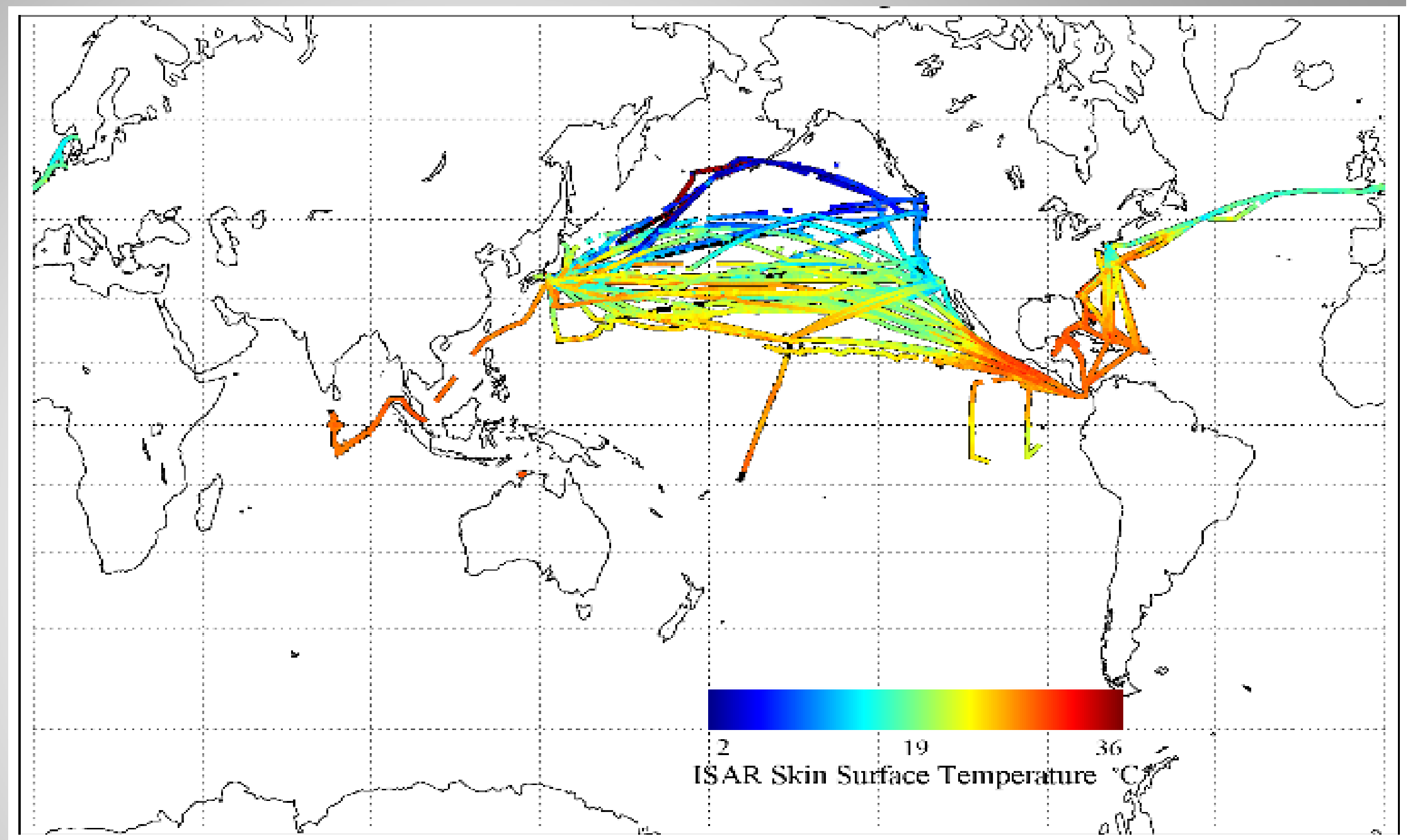
Skin SST measurements from R/V *Knorr*. January – March 2013.

M-AERIs, new and old, on R/V *Knorr*. Transit from Woods Hole to Cape Town, and an Agulhas mooring recovery cruise.

M-AERIs are Fourier Transform Infrared interferometers with two internal blackbody calibration targets. Pre- & post-deployment lab calibration against NIST-traceable calibrators.

Ship-board IR filter radiometers: ISARs

M/V *Andromeda Leader*



ISARs are autonomous filter radiometers with two internal blackbody calibration targets.

Pre- & post-deployment lab calibration against NIST-traceable calibrators.

Data relayed in real-time by Iridium.

M/V *Horizon Spirit*

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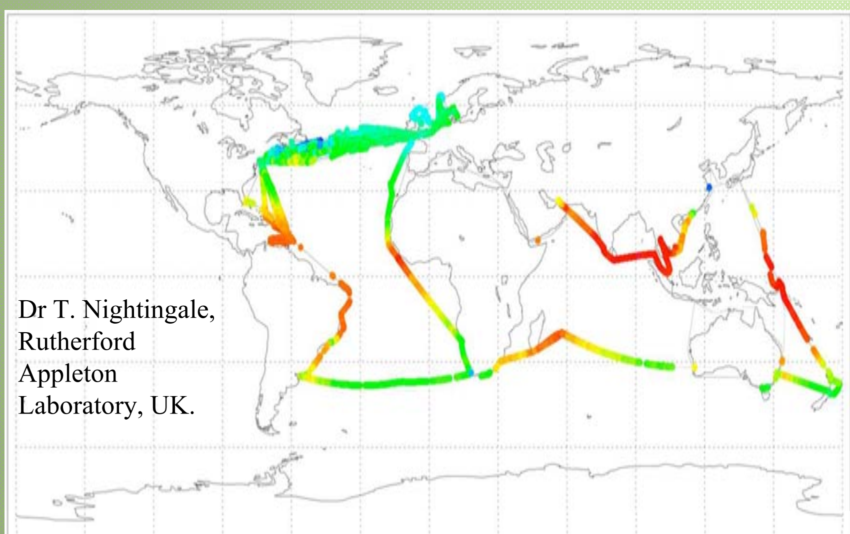
Ship-board IR filter radiometers

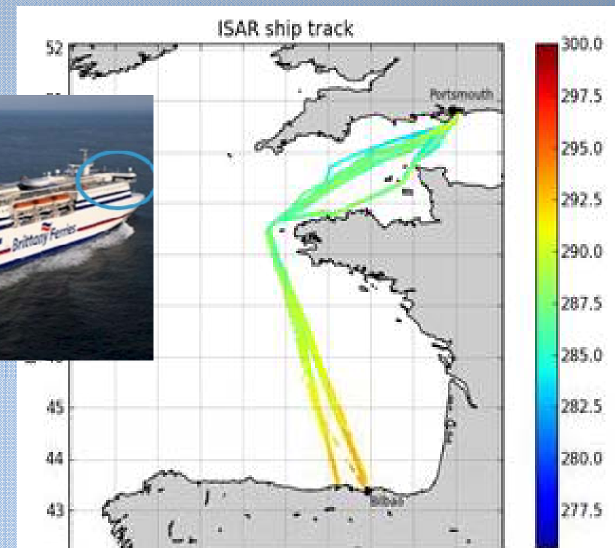
Several groups deploy filter radiometers on ship for satellite SST validation. The European radiometers are supported by ESA for Envisat (past) and Sentinal-3 (future) validation.

SISTeR (Scanning Infrared Sea Surface Temperature Radiometer) deployed by Rutherford Appleton Lab (UK) on Queen Mary II.



Dr T. Nightingale, Rutherford Appleton Laboratory, UK.

ISAR deployed by University of Southampton (UK) on Brittany Ferries



Dr W. Wimmer, University of Southampton, UK.

Others in Japan, China, Australia, USA…..

Within the framework of GHRSST and ISSI Study Group, a consistent format for radiometer data and metadata is being defined to facilitate data exchange.

The archive will be the British Oceanographic Data Centre.

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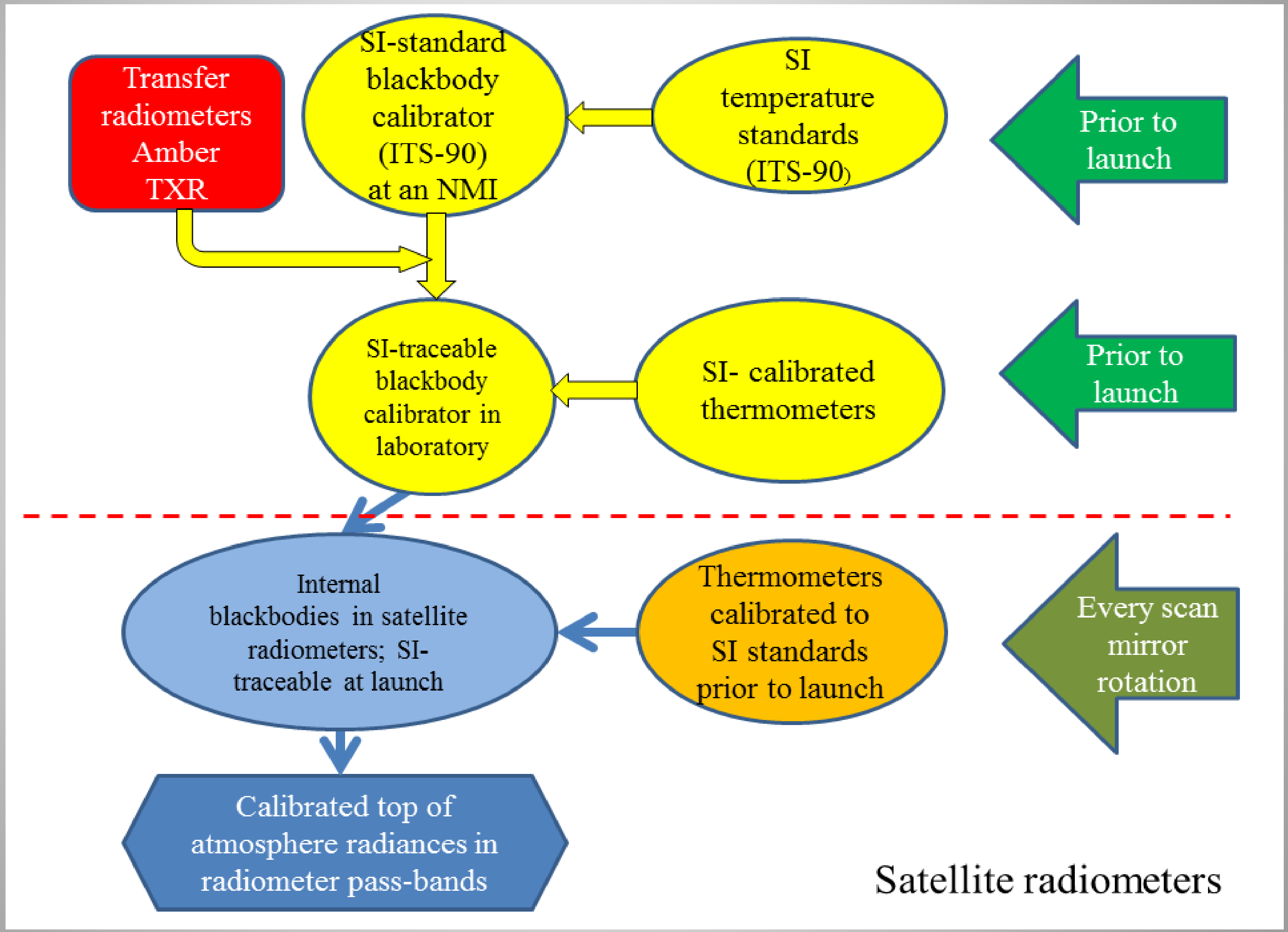
Calibrating satellite radiometers



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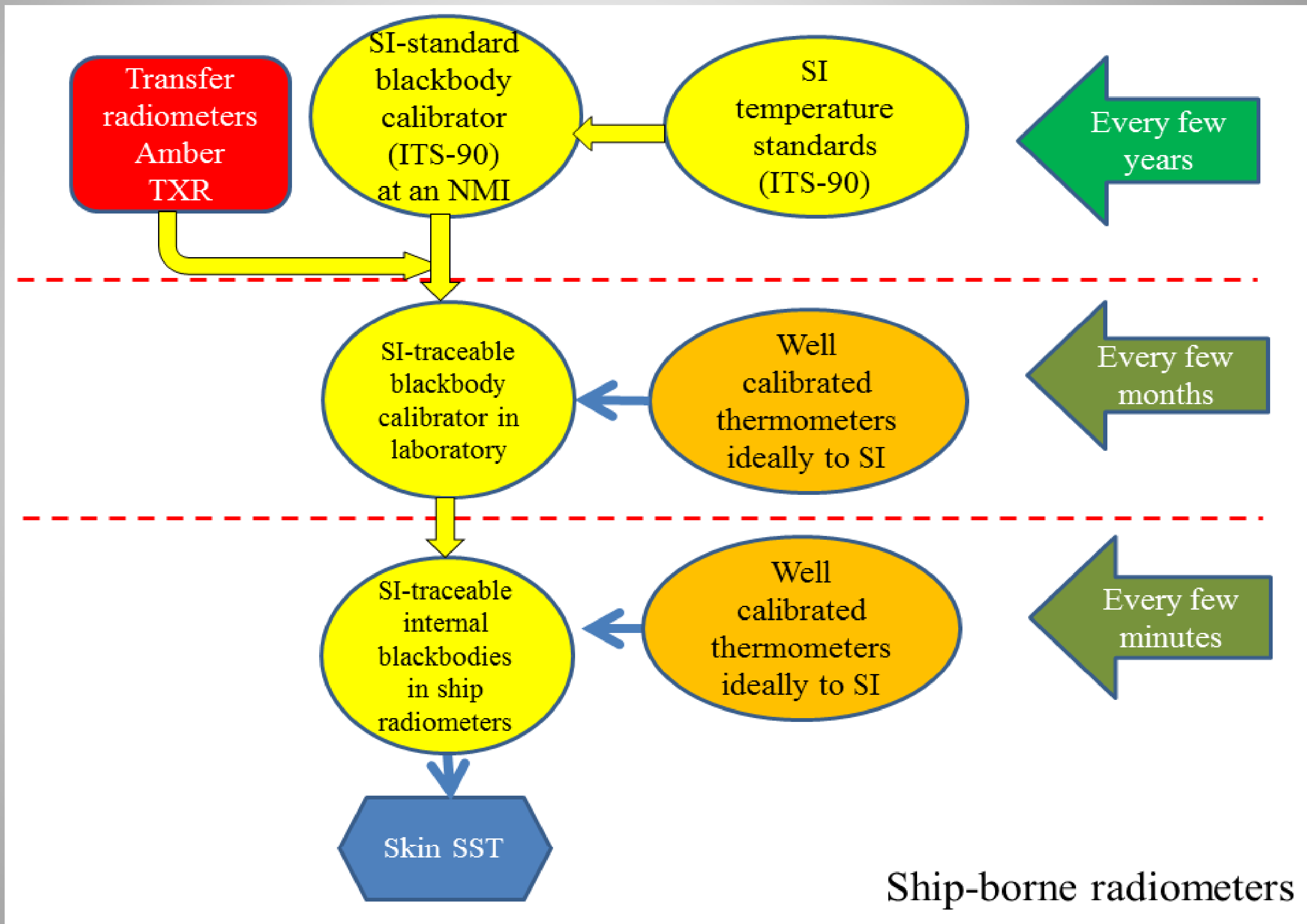
Calibrating ship-board radiometers



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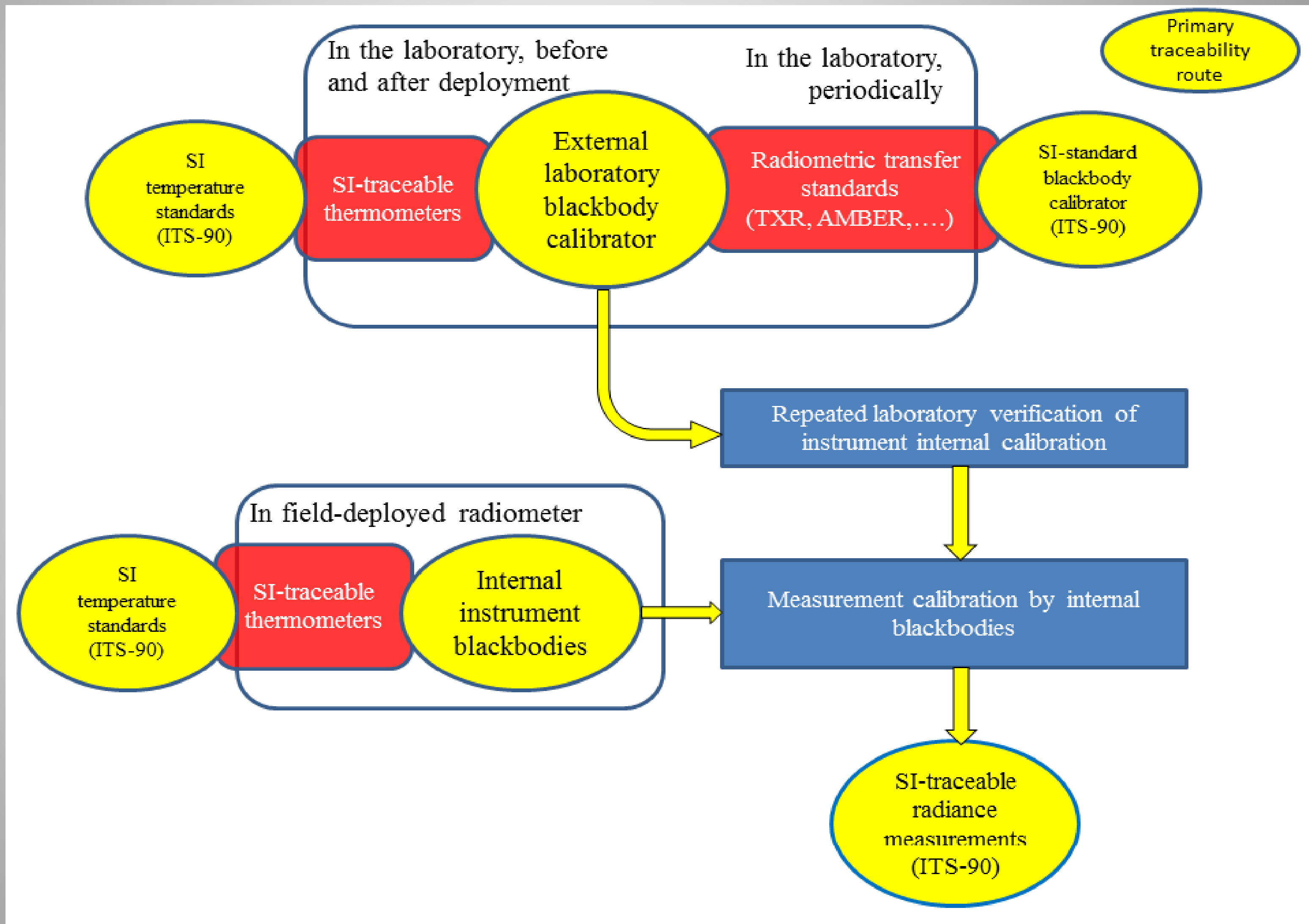
SI-traceability of ship-board radiometers



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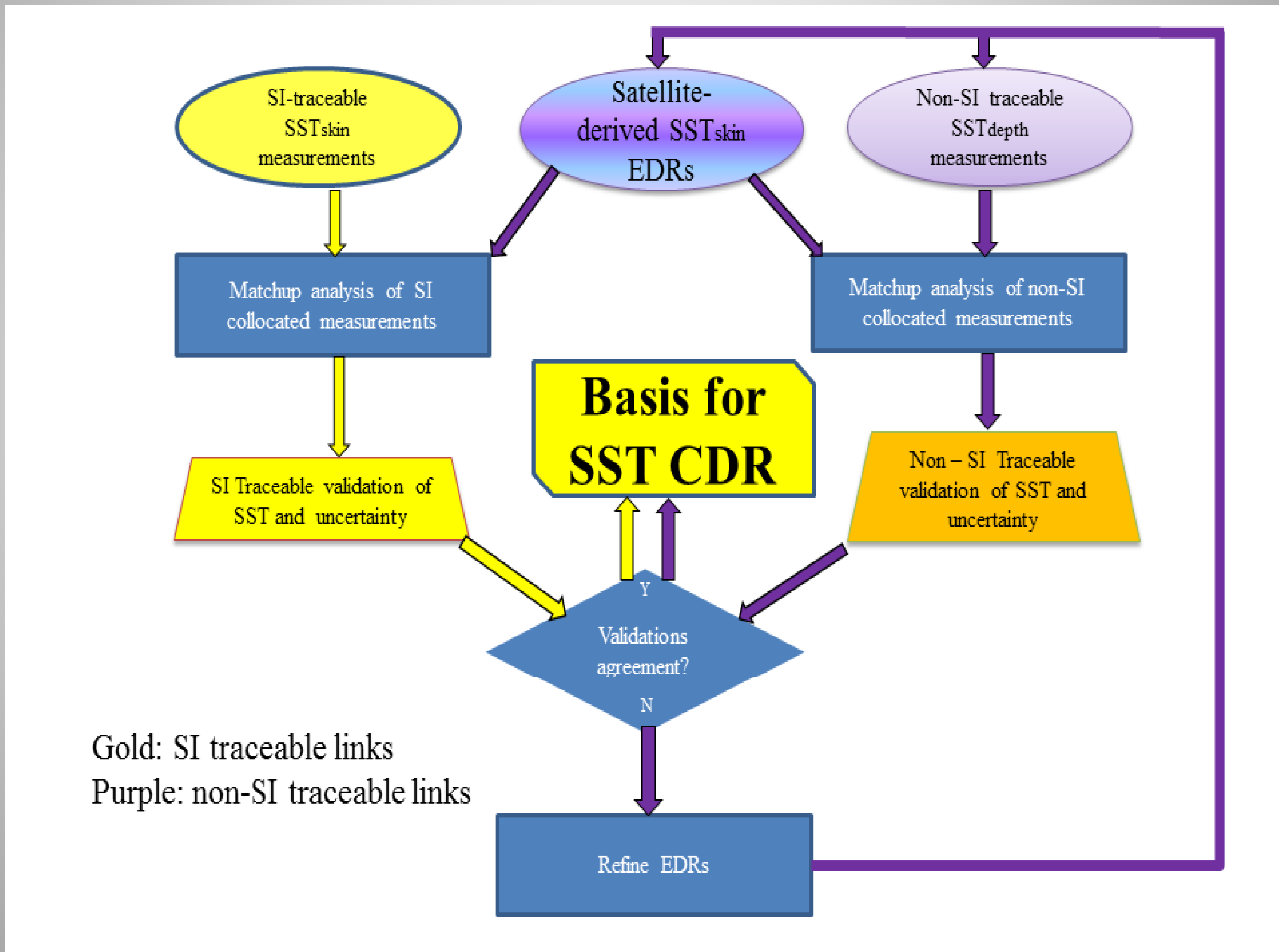
Transfer SI-traceability to satellite retrievals



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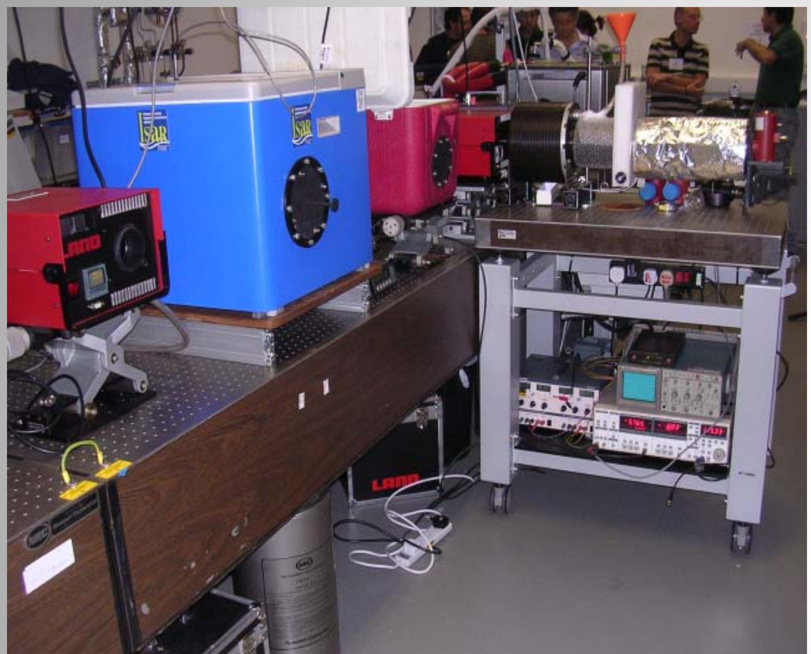
SI-transfer standards



Laboratory blackbodies to assess the uncertainties in the ship-borne radiometer measurements pre- and post-launch calibration being compared to SI-standard references by AMBER at NPL (left) and by TXR at Miami (right).

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Summary - CDR

- Target accuracies and stability are very challenging.
- Temperature is an SI base variable – huge advantage.
- Converging on approach to generating SST CDRs from satellite measurements:
  - Repeated characterization of laboratory black body targets used to assess the internal calibration of ship-board radiometers provides traceability to SI standards.
  - Comparisons between satellite SST retrievals and collocated ship-radiometer skin SSTs provides SI-traceable uncertainties in the satellite-derived fields.
  - Use of ship-radiometers over multiple satellite missions provides the basis of satellite-derived SST Climate Data Records.

Summary

CDR generation requires accurate, stable and well characterized MODIS Brightness Temperatures over the long duration of the missions!

Summary – SST

- We have tools to measure skin temperature from ships
- Physics of causes of temperature variability are reasonably well defined.
- Challenges are in developing sufficiently accurate models and in measuring forcing parameters (wind, surface radiation,...)

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SI-traceable calibration of ship-board radiometers

The NIST EOS TXR

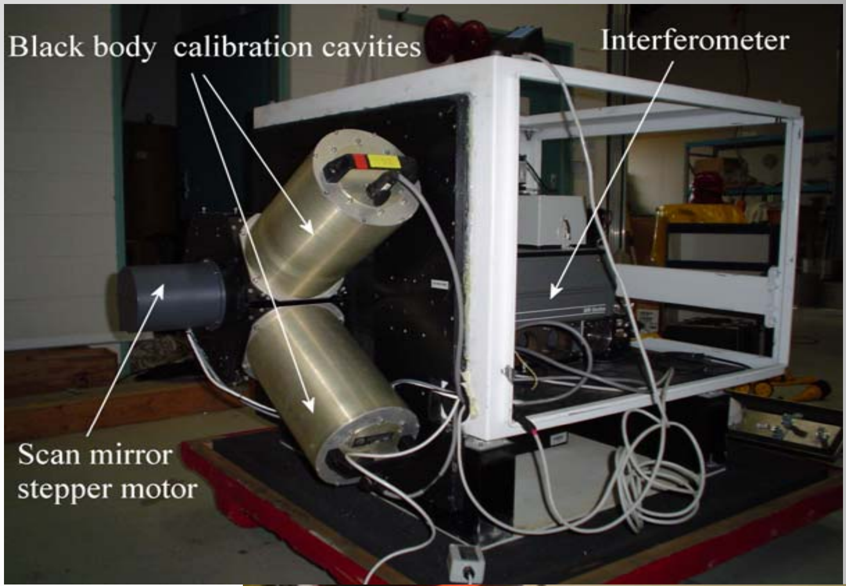
Unique EOS Standard Cryogenic detectors (liquid N_2)
λ= 5 & 10μm

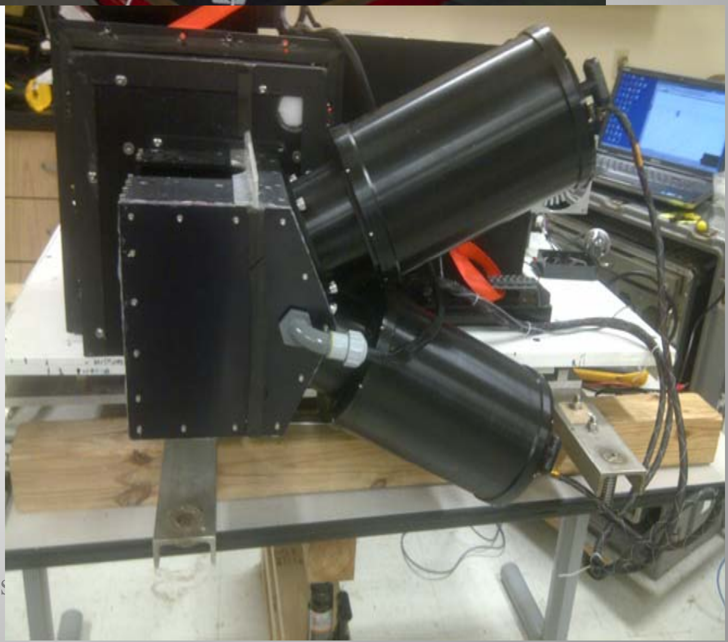
Rice, J. P. and B. C. Johnson, 1998. The NIST **EOS Thermal-Infrared Transfer Radiometer,** ***Metrologia*****, 35, 505-509.**

Rice, J.P. et al., 2004. The Miami2001 Infrared Radiometer Calibration and Intercomparison: 1. Laboratory Characterization of Blackbody Targets. *Journal of Atmospheric and Oceanic Technology*, 21, 258-267

NIST water-bath black-body calibration target

See: Fowler, J. B., 1995. A third generation water bath based blackbody source, *J. Res. Natl. Inst. Stand. Technol*., 100, 591-599





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SST Climate Data Records from satellites

- If we can deal with atmospheric effects to derive accurate skin SSTs
- And if we can deal with diurnal heating and cooling
- And if we can deal with variability in the skin layer
- Then can we generate a Climate Data Record from satellite measurements?

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Sea-Surface Temperature in Climate

SST is an Essential Climate Variable:

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The Essential Climate Variables

Domain	Essential Climate Variables	
Atmospheric (over land, sea and ice)	Surface:	Air temperature, **precipitation**, air pressure, surface radiation budget, wind speed and direction, water vapour.
	Upper air:	**Earth radiation budget (including solar irradiance), upper air temperature (including MSU radiances), wind speed and direction, water vapour, cloud properties.**
	Composition:	**Carbon dioxide**, methane, **ozone**, other long-lived greenhouse gases, **aerosol properties.**
Oceanic	Surface:	**Sea surface temperature**, sea surface salinity, **sea level, sea state, sea ice**, currents, **ocean colour (for biological activity)**, carbon dioxide partial pressure.
	Sub-surface:	Temperature, **salinity**, currents, nutrients, carbon, ocean tracers, phytoplankton.
Terrestrial		River discharge, water use, ground water, **lake levels, snow cover, glaciers and ice caps**, permafrost and seasonally-frozen ground, **albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation (fAPAR), leaf area index (LAI), biomass, fire disturbance, soil moisture.**

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Marine-Atmospheric Emitted Radiance Interferometer (M-AERI)

Specifications

Spectral interval	~3 to ~18μm
Spectral resolution	0.5 cm^{-1}
Interferogram rate	1Hz
Aperture	2.5 cm
Detectors	InSb, HgCdTe
Detector temperature	78°K
Calibration	Two black-body cavities
SST retrieval uncertainty	<< 0.1K (absolute)

Laboratory tests of M-AERI accuracy

Target Temp.	LW (980-985 cm^{-1})	SW (2510-2515 cm^{-1})
20°C	+0.013 K	+0.010 K
30°C	-0.024 K	-0.030 K
60°C	-0.122 K	-0.086 K

The mean discrepancies in the M-AERI 02 measurements of the NIST water bath blackbody calibration target in two spectral intervals where the atmosphere absorption and emission are low. Discrepancies are M-AERI minus NIST temperatures.

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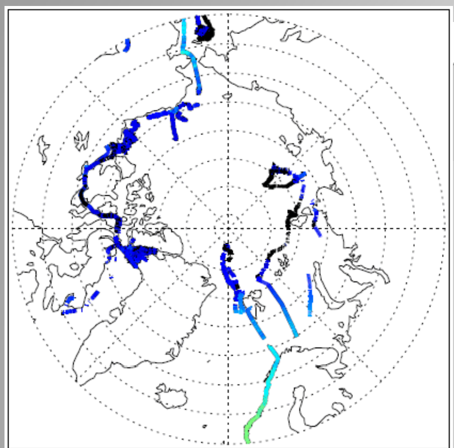
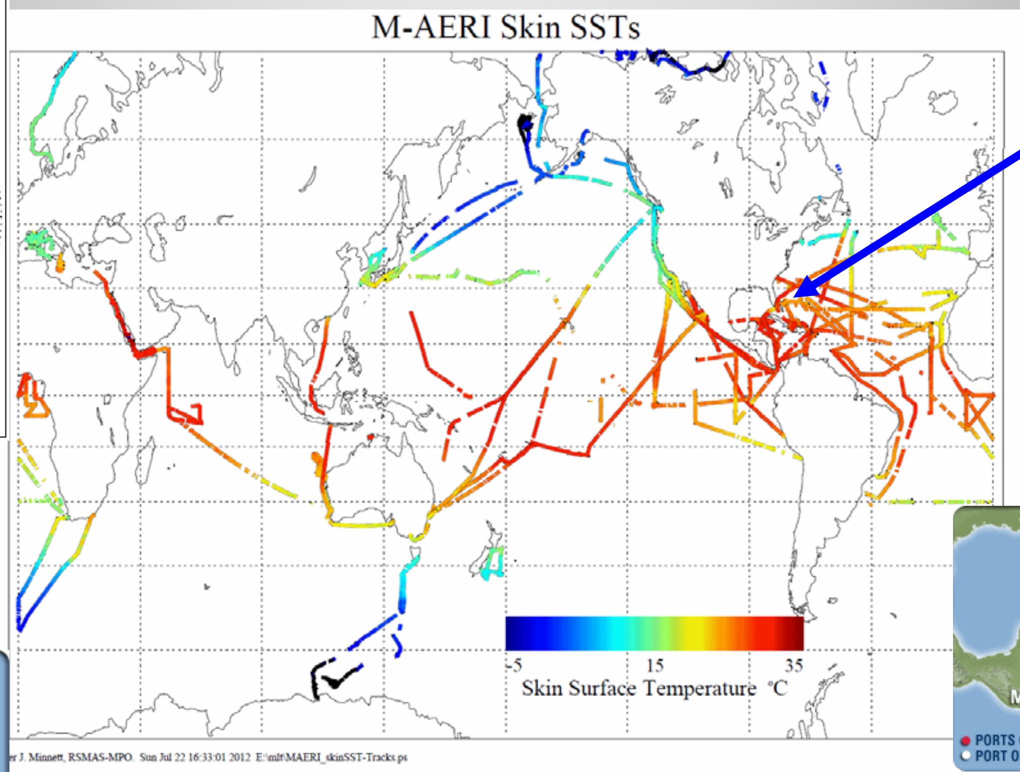
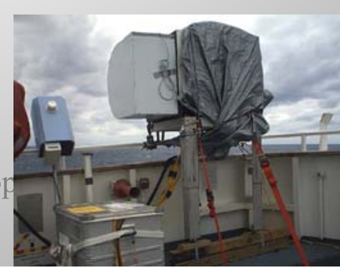
M-AERI cruises for MODIS validation

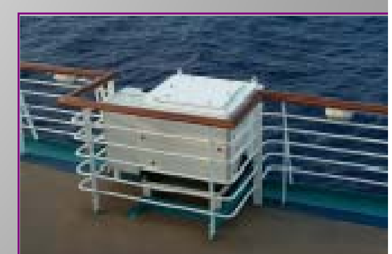




Explorer of the Seas

Explorer of the Seas: near continuous operation December 2000 – December 2007.





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